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An Experimental Investigation on the Drying of Sliced Food Products in Centrifugal Fluidized Bed[1]

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An experimental investigation on the fluidization and drying characteristics of sliced food products in a centrifugal fluidized bed dryer was carried out. The rotating speed ranges from 300 rpm to 500 rpm. Sliced potato and radish were used as the testing materials. The results show that the sliced materials can be fluidized well in the centrifugal fluidized bed. The fluidized curve has a maximum value and the critical fluidized velocities vary with the type of the test material, its shape and dimension as well as operating parameters. The sliced food materials can be dried very well and fast in the centrifugal fluidized bed with a large productivity. The factors that influence the drying process were examined and discussed. The final shape and inner structure of the dried products were observed. The water recovery characteristics of the dried products were also investigated.

Keywords: drying, rewet, sliced product, centrifugal fluidized bed.

INTRODUCTION

Centrifugal fluidized bed (CFB) drying is a new technology in which the wet material is undergone a highly enhanced heat and mass transfer process in a centrifugal force field by rotating the bed. The bed is essentially a cylindrical basket rotating around its symmetric axis with porous cylindrical wall. The drying material is introduced into the basket and forced to form an annular layer at the circumference of the basket due to the large centrifugal forces produced by the rotation. The gas is injected inward through the porous cylindrical wall and the bed begins to fluidize when the forces exerted on the material by the fluidizing medium balance the centrifugal forces. Instead of having a fixed gravitational field as in a vertical bed, the body force in a centrifugal bed becomes an adjustable parameter that can be determined by the rotation speed and the basket radius. Minimum fluidization can, in principle, be achieved at any gas flow rate by changing the rotating speed of the bed. By using a strong centrifugal field much greater than gravity, the bed is able to withstand a large gas flow rate without the formation of large bubbles seriously. Thus the gas-solid contact at high gas flow rate is improved and the heat and mass transfer can be achieved during the drying process. For this reason, centrifugal fluidized bed dryer has received much attention in drying industry.

Only a few research works dealing with the drying of food products in the centrifugal fluidized bed could be found in literature. Lazar et al (1971–1979) and Brown (1972) have conducted the drying process in a centrifugal fluidized bed for sliced fruits and vegetable, while Carlson (1976) has took an investigation on the drying of fast rice in the centrifugal fluidized bed. These research works are very instructive, but they are mainly focused on the possibility of an industrial application for CFB. The flow behavior and drying characteristics in CFB is very complicated and still not very clear, but it is necessary for the design purpose of a centrifugal fluidized bed dryer. In this paper, an experimental study on fluidization behavior

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Symbols

G	mass flow rate of gas kg/s
H	moisture content of gas kg/kg
Lo	fixed bed thickness m
Mw	weight of dried material kg
n	rotating speed of the bed rpm
P	pressure drop kPa
R	drying rate kg/m^{2}s
S	drying area m^2
T	temperature °C
U_0	superficial gas velocity m/s
W	water content (wet) %
x	moisture content kg/kg

and drying characteristics of sliced food products in a centrifugal fluidized bed were performed and the main factors which influence the drying process were examined and discussed. The final shape and inner construction of the dried products were observed and discussed. The water recovery characteristics of the dried products were also investigated.

EXPERIMENTAL APPARATUS

A schematic diagram of the experimental apparatus is shown in Figure 1. A cylindrical basket rotated about a horizontal axis is mounted in a sealed cylindrical casing. The basket is of 200mm in diameter and 80mm in width. The side surface of the basket having 3mm diameter holes on it serves as a gas distributor, which has an open area of 22.7%. A 200 mesh stainless steel screen is coated inside surface to prevent the bed material from leaking out. There is one hole of 80mm diameter located at the center of the end wall of the basket to exit the gas. A variable speed motor is used to rotate this basket by means of a shaft connected to another end wall of the basket. The Rotational speeds of the motor are measured by use of a LZ–45 revolution counter.

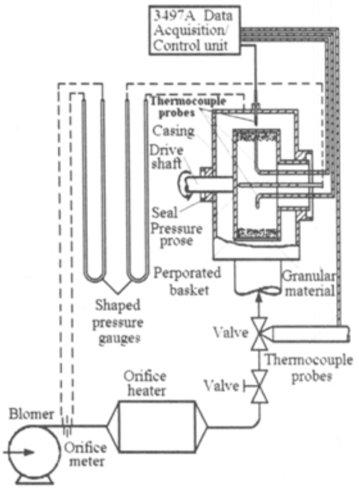

Fig.1 Experimental apparatus

Air is blown in from a blower. The mass flow rates of air are measured using an orifice meter. Air is heated using an electric heater. A tee valve is used to control the flow direction. After the air temperature is steady at the desired value (about 100°C), the drying experiments begin by turning the tee valve on, the hot air flows through the distributor to the bed and then is exhausted into atmosphere. The pressure drop is measured by an U–shaped pressure gauge.

A pressure probe is stretched into the basket along the centerline 10 mm away from another end wall of the basket. Experiments are also conducted without the bed material to obtain the pressure difference across the distributor under the same operating conditions. The pressure drop through the bed is, then, calculated by

$$\Delta P_{\mathrm{Bed}} = \Delta P_{\mathrm{Total}} - \Delta P_{\mathrm{Distributor}}$$

The inlet gas temperature, the outlet gas temperature and the bed temperatures at various positions vs. time are measured using the bare thermocouple probes and the data are recorded by a 3497A data acquisition / control unit. The moisture contents of the test material during the drying process are measured by the moisture balance method in gas phase, that is, by measuring the inlet and outlet wetabilities in gas phase with wet and dry bulb thermometers.

The water balance at the time interval from t_j to $t_{j=1}$ is

$$G \int_{t_j}^{t_{j+1}} (H_{out} - H_{in})dt = -M_s \int_{x_j}^{x_{j+1}} dx$$

thus the moisture content of the test material at time t_{j+1} is

$$x_{j+1} = x_j - \frac{G}{M_s} \int_{t_j}^{t_{j+1}} (H_{out} - H_in)dt(2)$$

By use of drying weight method for a test material sample to obtain the initial moisture content we can get the moisture content variation with the time, and thus the drying rate can be calculated as

$$R = -\frac{M_s}{S_p}\frac{dx}{dt}$$

where the drying surface Sp is taken as the total surface area of the test material.

The fresh potato and radish are used as the test materials. After cleaning and skinning they are cut into 5 × 5 × 5 mm blocks and 10 × 10 × 1 mm pieces for the drying test.

RESULTS AND DISCUSSION

A. The Pressure Drop of the Bed and Initial Fluidization Character

Fig.2 shows the variations of the bed pressure drop with the superficial gas velocity for a block and a piece potato bed at different rotating speeds during the drying tests. It is obvious that the pressure drop curve has a maximum value that corresponds with the critical fluidization point. In the initial fluidizing stage the pressure drop increases with increasing the gas velocity slowly. After reaching the critical point the pressure drop will decrease with increasing the gas velocity. This is because the self-lock phenomenon of the sliced material under a centrifugal force field will be weakened and the bed becomes uniform. It causes the flow resistance decreasing. Decreasing the bed rotating speed would decrease the bed pressure drop and the critical gas velocity remarkably as also shown in Fig.2. This is because the decrease of the bed rotating speed would weaken the centrifugal force field and cause the flow resistance decreasing. It can be seen from Fig.2 that the critical fluidized velocity for piece material is somewhat smaller than that of block material owing to the larger upwind surface area for piece material. Furthermore the pressure drop of the piece material bed is also smaller than that of the block material bed because the piece material has better fluidization character in the centrifugal fluidized bed. It is examined that the existed initial fluidizing relationships obtained from the theoretical model for granular material do not fit the sliced material. The initial fluidizing conditions for the sliced material with different shapes should be determined experimentally and individually.

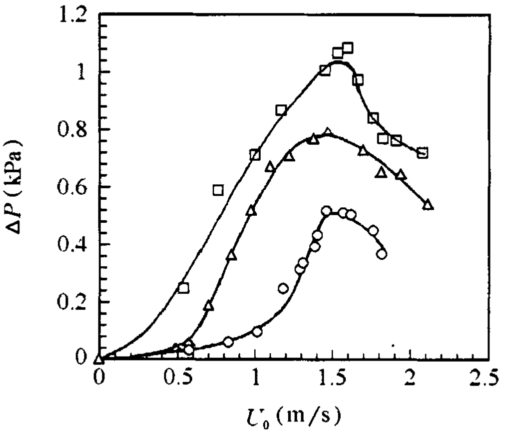

Fig.2 Pressure drop curves

△ piece potato $M = 0.52$kg, $n = 300$rpm
☐ block potato $M = 0.57$kg, n=300rpm
○ block potato $M = 0.57$kg $n = 250$rpm

B. Drying Curves

A typical drying curve in the intermittent drying process is shown in Fig.3. It is obvious that the sliced potato has similar drying character in the centrifugal fluidized bed to the conventional drying process. At the beginning there is a short initial period. In this period the bed material is preheated and the bed temperature approaches quickly to a stable value, the drying rate increases very fast. This initial period is followed by the period of constant rate of drying. In the constant rate period, the surface of the test material is covered with a thin water film. The heat transferred from the gas flow to the material is used completely to evaporate the moisture, so that the temperature of the sliced material remains at an equilibrium temperature and the drying rate is at the maximum value. Because the main moisture contents in the potato are the cell water, the constant rate period is then very short. The most important drying process is complete in the falling rate period followed. In the falling rate period the dry layer appears and becomes thicker gradually near the surface owing to the larger transport resistance of the inner moisture outward. It causes the heat transfer resistance increasing and the drying rate decreasing fast in the first stage. After the temperature of the dried layer increases to a certain value the decrease of the drying rate become slowly. This indicates that the falling rate period for the sliced potato in the centrifugal fluidized bed dryer could be divided into two different stages. It is important to the engineering design and operation.

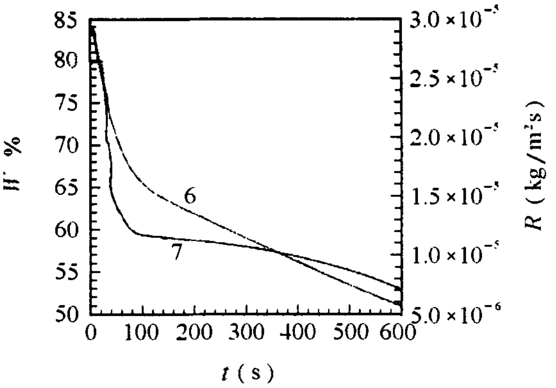

Fig.3 Variations of wet content (curve 6) and drying rate (curve 7) in the test

The experimental results show that the piece potato in drying process has larger drying rate and shorter drying time than the block potato in the centrifugal fluidized bed. This is because the transport distance of the moisture from inner cell to the outside evaporating surface in the piece material is much more short than in the block material, especially the second stage of the falling rate period is shorter for the piece material during the drying process. In general, because the sliced material could be fluidized and mixed very well in the centrifugal fluidized bed, the drying time is extremely short. For example the drying time is 15 times longer in the conventional tunnel dryer than in the centrifugal fluidized bed for sliced potato.

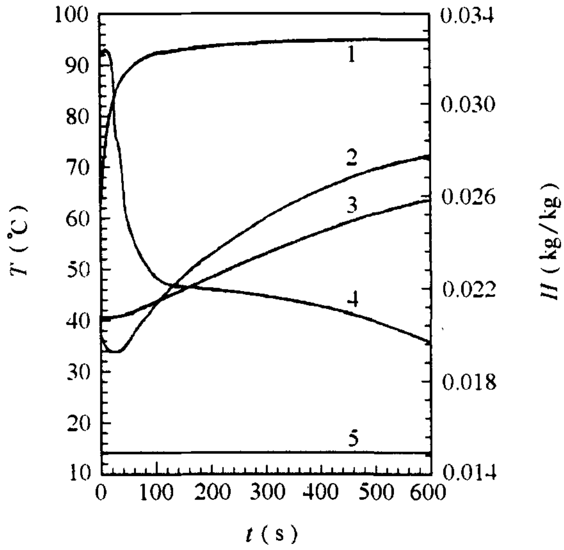

Fig.4 Temperature and enthalpy variations in drying process

C. Temperature Variations in the Drying Process

Fig.4 shows the variations of inlet gas temperature (curve1) and enthalpy (curve5), outlet gas temperature (curve3) and enthalpy (curve4), bed temperature (curve2) during the intermittent drying process in the centrifugal fluidized bed. The results show that the bed temperature increases gradually in almost whole process except a short initial time duration in which a large amount of surface water is evaporated and the bed temperature keeps almost constant. From the enthalpy curve one can also see clearly that there exist two stages with different drying characters in the falling rate period. It is expected that these two stages might be changed with different type of food material.

D. Influences of the Operation Parameters

The experimental results show that the drying rate in the constant rate period and in the first stage of the falling rate period would increase with increasing gas velocity at low gas velocity range. Thus the total drying time would be shorten. But when the gas velocity increases to a certain value, the constant rate period would disappear and the first stage of the falling rate period would be shortened and the second stage would be prolonged. The total drying time keeps almost unchanged, this is because most water content in potato is the inner cell water and the main drying process is within the second stage of the falling rate period. With the increase of inlet gas temperature, the drying rates in all drying periods increase and the total drying time will be shortened. But the increase of gas temperature would be limited by the quality of the dried food products. In our test the best inlet gas temperature is about 100–110°C.

The experimental results also show that piece radish with given dimensions has larger drying rate than that of piece potato under the same operating conditions. This is because the microstructure of the test examples indicate that radish has larger cell structure with more regular arrangement than potato and further more the liquid in radish cell is less viscous, these structure characters cause radish to be easy to dry. At the same gas velocity, the decrease of the bed rotating speed will enhance the fluidized degree of the bed and heat mass transfer between gas and solid phase, thus the drying rate will be larger and the drying process will be much uniform in the whole bed. The maximum operating gas velocity in the centrifugal fluidized bed should be lower than the terminal gas velocity. Thus when people wants to enhance the drying process by increasing gas velocity in the centrifugal fluidized bed dryer, they must increase the bed rotating speed simultaneously to avoid the drying material to blow out of the bed. Theoretically, the bed can be operated in the optimum fluidized condition at any gas velocity by regulating the bed rotating speed in the centrifugal fluidized bed.

E. Deformation of the Dried Products and Water Recovering

The shapes and their inner structure of the dried block potato after drying at different drying conditions are shown in Fig.5

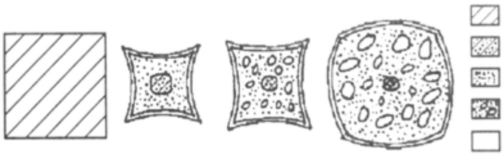

Fig.5 The shapes and inner structure of the dried block potato a. Initial shape b. 80–90°C c. 100–110°C d. > 110°C

The potato block under low temperature drying (80–90°C) would shrink up as shown in Fig.5b. In this case the products after fast drying in the centrifugal fluidized bed have a dried region with a uniform dense structure and a small wet nucleus in the center. Increasing gas temperature to 100–110°C, the gas cavities would appear in the dried region (Fig.5c) owing to the expansion of water vapor. When the drying process is conducted at higher temperature conditions, the dried products would expand as shown in Fig.5d. In this case the wet nucleus is smaller but still existed, the gas cavities in the dried region become larger. To drying these wet nuclei, it needs a relative long time and would no longer suit to proceed such further drying process in the centrifugal fluidized bed dryer.

The water recovering tests were made by put the dried products in the water. The rewetting process need to last about 5–20 minutes depending on the drying regime and material structure. The results show that all these dried products can almost be recovered to the initial state after rewetting. The dried products with the gas cavities, especially for expanding products would be recovered better and fast while the dried products with dense structure and shrinking shape would be recovered longer and hard to fully recover. The results also show that all dried products can not be recovered to their original crisp characteristics after rewetting operation.

CONCLUSIONS

1. The sliced food products can be fluidized and mixed very well in the centrifugal fluidized bed, the pressure drop curve has a maximum value and the critical fluidized parameters would vary with shape, dimension of the drying products and the material itself, as well as operating conditions.
2. The sliced food products can be dried very well and efficiently. The main process of the drying is within the falling rate period, the drying rate depends on shape, dimension and material of the drying products, as well as the operating conditions.
3. The deformation and recovering character depend on the gas temperature, gas velocity and product itself. The state of the dried product can be well controlled by regulating the bed rotating speed and gas temperature in the centrifugal fluidized bed.
4. The dried sliced food products in the centrifugal fluidized bed have better water recovering characteristics.

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